

Hyperspectral Imager for Coastal Ocean (HICO)

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LONG-TERM GOALS

The long term goal of the Hyperspectral Imager for Coastal Ocean (HICO) program is to demonstrate the utility of maritime imaging for naval applications in the littoral ocean from a space borne platform. The coastal ocean is a dark target and visible light constitutes the only part of the electromagnetic spectrum that sufficiently penetrates the water column to sense the water and seafloor properties. Analysis has shown that maritime hyperspectral imaging is the only remote sensing technique that is able to deconvolve the complicated coastal scene (Lee and Carder, 2002). The spectral content of hyperspectral data can give information on the depth and characteristics of the seafloor and undersea objects.

The Navy's "Sea Strike" mission requires precise knowledge and modeling of the littoral battlespace in denied areas of the globe. The emphasis on littoral tactics for precise amphibious assault, special forces insertion and mine warfare drive the need for improved capability. Space borne maritime hyperspectral imagery and its derived products such as bathymetry, bottom type, water clarity and beach traffic will be used to demonstrate the effectiveness of using hyperspectral data for characterizing the littoral battlefield.

The HICO program will demonstrate the use of space borne hyperspectral methods to detect submerged objects, the retrieval of environmental data products of value to Naval forces, and the development of coupled physical and bio-optical models of coastal ocean sites globally.

OBJECTIVES

The objective of the HICO program is to design and build a spectrometer that will meet the requirements for imaging littoral regions of the worlds' oceans from the International Space Station (ISS). The system is designed to meet a set of key requirements specifically designed to optimize the performance of the hyperspectral system from a space borne platform. NOVASOL is responsible for the design of the spectrometer and the collecting telescope that is mounted to the front of the spectrometer.

A hyperspectral imager records a contiguous spectrum of the light reflected by each pixel in a scene. This spectral information is exploited during data processing and product retrieval. A hyperspectral imager contains a telescope to collect light from the scene, a spectrally dispersive element, a focal plane array to convert the dispersed light to an electrical signal, data collection and storage electronics,

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and a system controller and power supply. The performance requirements for maritime hyperspectral imaging, based on NRL experience (Davis and Carder, 1997; Davis, et al., 2002), are summarized in Table 1.

Table 1. Key performance parameters for the HICO maritime hyperspectral imager.

Parameter	Requirement for Maritime Hyperspectral Imaging from Space	Rationale
Off-nadir pointing	+/-30 deg (Goal +70/-45 deg)	To increase scene access frequency
Spectral Range	Minimum 400 to 860 nm (Goal 380-1000 nm)	water-penetrating wavelengths and NIR for atmospheric correction
Spectral Channel Width	10 nm (goal 5 nm)	Sufficient resolution to resolve spectral features
Signal to Noise Ratio	> 200 to 1 for a 5% surface albedo scene	Provides adequate residual SNR after atmospheric removal
Polarization Sensitivity	< 5% (< 2% goal)	Sensor response to be insensitive to polarization of scene light
Ground Sample Distance	100 meters (\pm 20%)	Comparable to scale of coastal features
Scene Size	Thousands of square kilometers	To encompass the scale of coastal dynamics
MTF	>0.35 at Nyquist spatial frequency of 0.5 cycles/pixel	To assure that the recorded signal is coming from the sampled GSD
Saturation	Shall not saturate when viewing a 95% albedo cloud	To be able to image dark ocean next to bright clouds
Spectral stray light	< 1% albedo error	To assure that the true spectrum is recorded
Long term stability	+/- 0.5% after calibration of the data	To assure a consistent data set over time for change detection
Jitter	< 0.5 pixel (highly dependent on spacecraft vibrations)	To assure that the image is not distorted during the collection period.
MTF	>0.35 at Nyquist spatial frequency of 0.5 cycles/pixel	To assure that the recorded signal is coming from the sampled GSD

The HICO sensor was designed to specifically meet the set of requirements in Table 1. Table two lists the specifications for the HICO spectrometer as derived from the requirements.

Table 2. Specifications for the HICO spectrometer and lens

Lens	Specification	Requirement
	Focal length	60 mm ($\pm 3\%$)
	FOV	7.6 degrees (i.e., ± 3.8 degrees)
	f-number	2.5 – 2.8 (set final value after assembly)
	Spectral range	0.38 – 1.0 μ
	Optical spot size	$< 7 \mu$ rms diameter
	Lateral color	$< 20\%$ of a 16 μ pixel = 3 μ
	Throughput	$\geq 90\%$ for all wavelengths
	Vignetting	none
Spectrometer	Specification	Requirement
	Spectral range and dispersion	0.38 – 1.0 μ over 4 mm ³
	Blaze wavelength	500 nm
	Slit width	16 μ
	Slit length	8.2 mm (= 16 $\mu \times 512$ pixels)
	f-number	2.5
	Final optical spot size	$< 10 \mu$ rms diameter (includes effect of lens)
	Spectral smile	< 2 nm of wavelength = 0.8 pixels = 12 μ
	Keystone	$< 20\%$ of a 16 μ pixel = 3 μ (includes effect of lens)
	Throughput	$\geq 50\%$ for all wavelengths in 0.4 – 0.76 μ band
		$\geq 30\%$ for 0.76 – 1 μ band
	Polarization sensitivity	$\leq 5\%$ (includes fold mirror)
	0-order beam dump	yes (reduces stray light)
	Stray light	no specific requirement, as low as possible

APPROACH

The HICO hyperspectral sensor includes the telescope lens and the spectrometer. NOVASOL was responsible for the design and build of the lens and spectrometer while NRL was responsible to supply the camera and order sorting filter that will be mounted to the camera. The spectrometer design is based on an Offner optical design which was chosen because of its low distortion properties specifically for both keystone and smile. An Offner design also provides high quality imaging at a low F number while allowing for a compact mechanical package. A high efficiency grating with an expected efficiency of 75% at the peak wavelength of 500 nm has been designed into the spectrometer. The grating is being procured from Bach Research. Collectively Bach Research employees have over 120 years experience in optical fabrication, optical coatings, diffraction gratings, and optical testing. The telescope lens was custom designed by NOVASOL in order to meet the field of view, f number, vignetting and throughput requirements. The lens has a telecentric focus at the slit (chief rays are parallel to the optical axis) and has chromatic correction over the entire wavelength range of 380 nm to 1000nm.

Since the spectrometer and telescope must survive a rocket launch and subsequent deployment on the outer structure of the International Space Station, the mechanical design is robust and contains only materials that are currently approved by NASA. The spectrometer and lens was designed to be hermetically sealed so that dry nitrogen gas can be inserted into the system.

WORK COMPLETED

NOVASOL procured all the materials to build the system and completed the assembly the spectrometer. The spectrometer is an F/2.5 system with a 7.6 FOV that meets the requirements listed in the Objectives section of this report. The spectrometer was also designed so that it can be hermetically sealed into one volume with the camera and used in a space environment. The mechanical design is rugged and the optical mounts were designed to withstand launch and deployment into space. Materials selected for use in the spectrometer were chosen by consulting the NASA materials data base. The adhesives used to bond the optics are all space grade epoxies or silicones and the o-rings used to seal the unit are also made of space grade rated material.

The spectrometer was built using a precisely aligned test set-up that allowed the assembly team to build the spectrometer using a dial indicator to precisely position the optics in reference to the slit. Since NRL chose not to supply the camera for the final assembly step, namely aligning the camera with the spectrograph, this final step will have to be performed at NRL. The components for mounting the camera to the spectrograph had been sent to NRL for a fit check. NOVASOL therefore does not anticipate any issues to arise during integration of the camera and spectrometer. The light output of the spectrograph was verified prior to delivery to ensure that the light can be focused in space. Figures 1 through 11 show the test set-up and illustrate the build and alignment of the spectrograph.

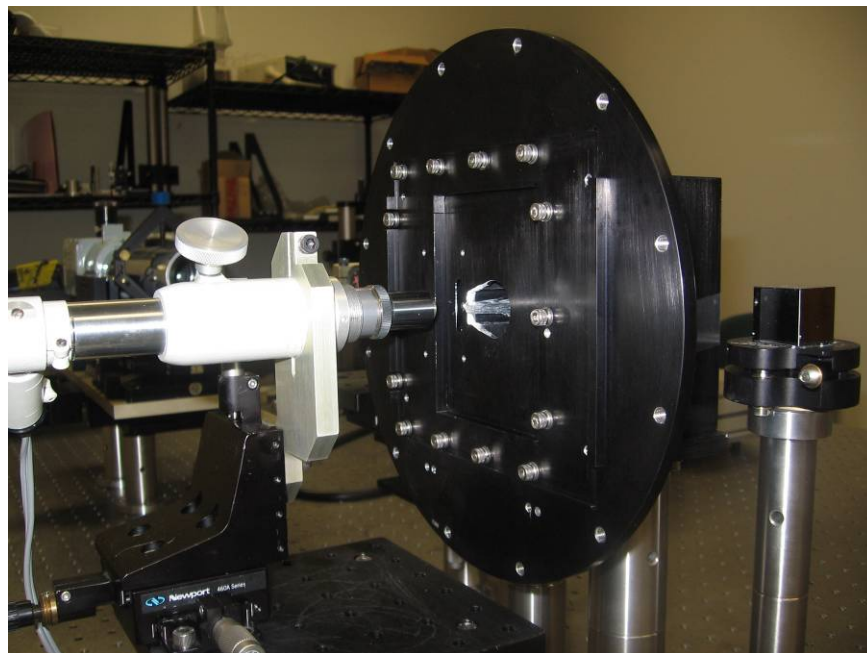


Figure 1: Microscope positioned to be focused at the center of curvature which allows the alignment of the two spherical mirrors.

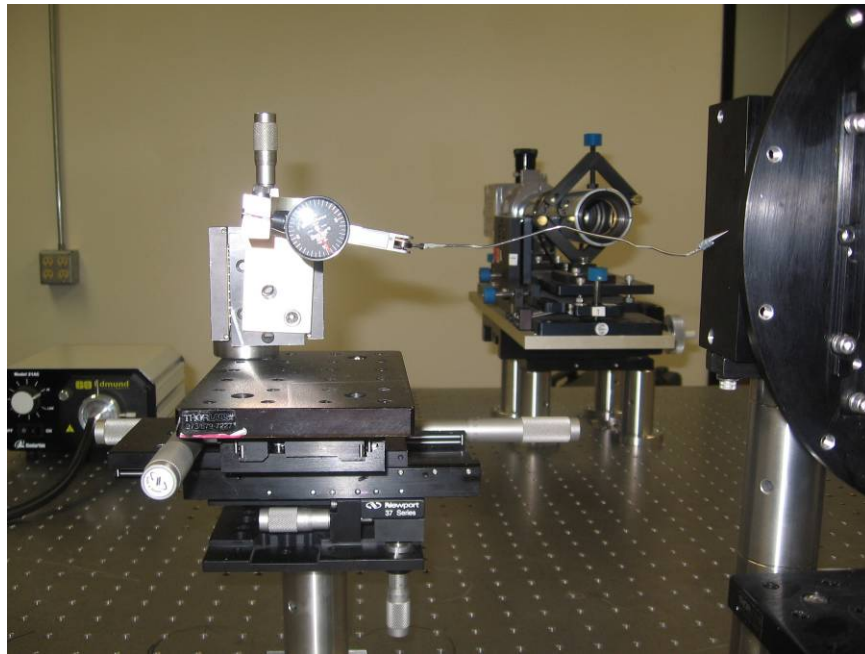


Figure 2: Dial Indicator and autocollimator used to insure the exact positioning of the fold mirror and grating.

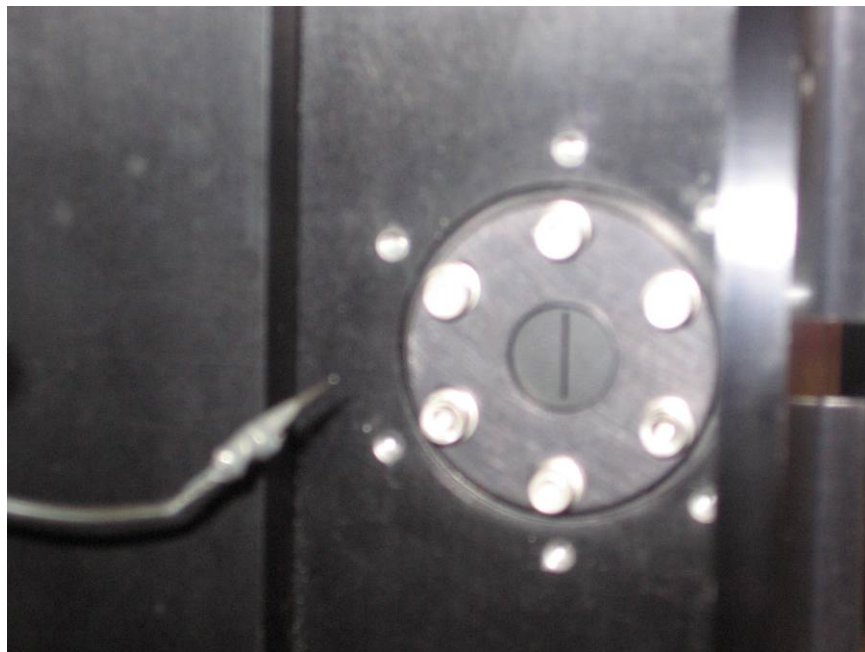


Figure 3: Close-up of the slit with indicator. The optics were positioned by referencing to the front and center of the slit.

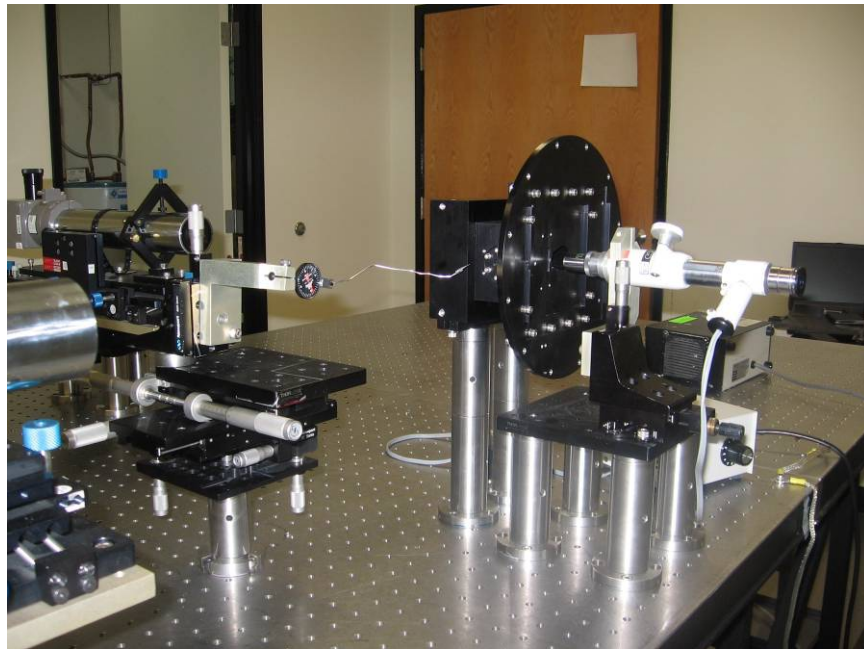


Figure 4: Test set-up showing two autocollimators and dial indicator.

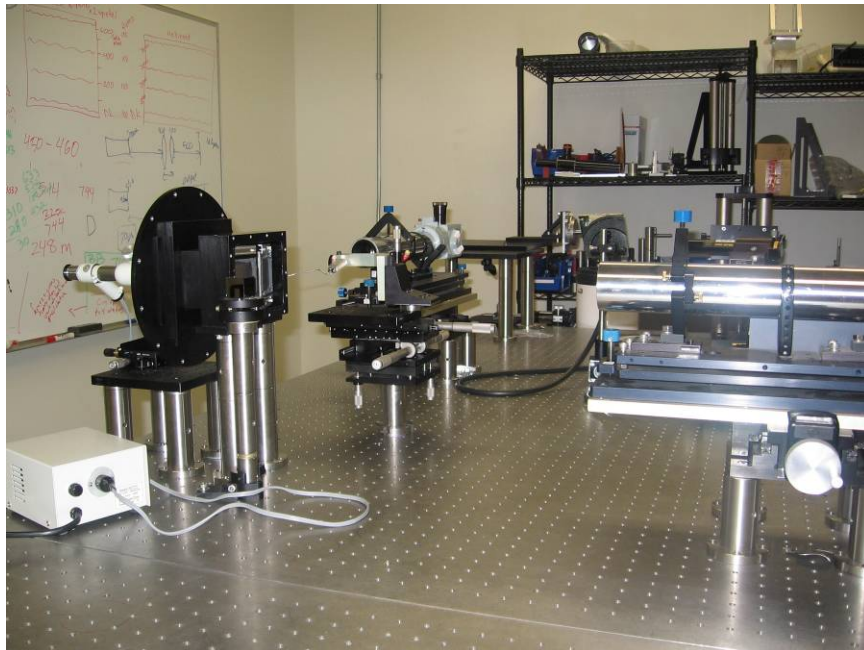


Figure 5: View of the set-up: two autocollimators, microscope and indicator on precisely aligned translation platforms.

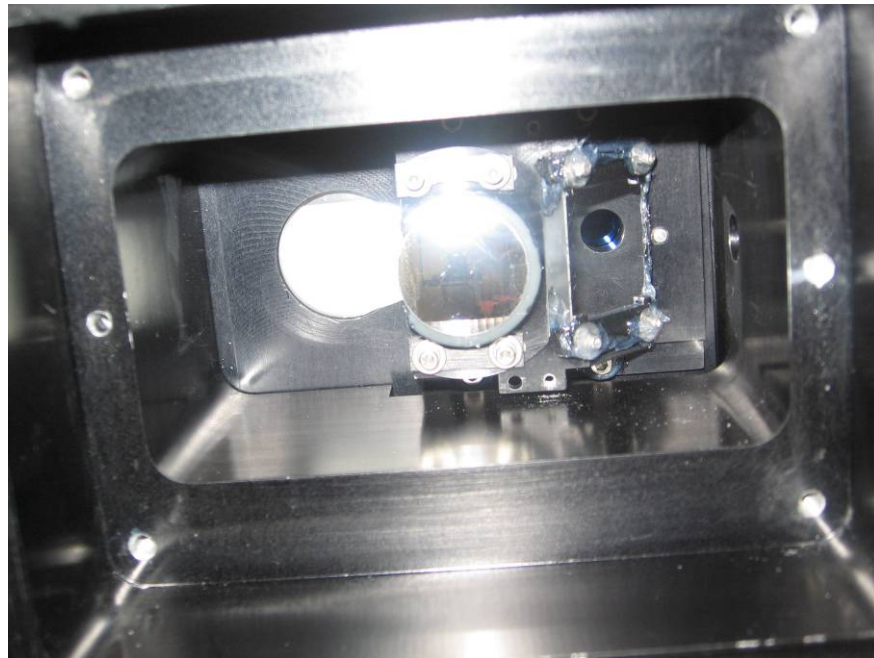


Figure 6: Turn mirror and grating in their mounts.

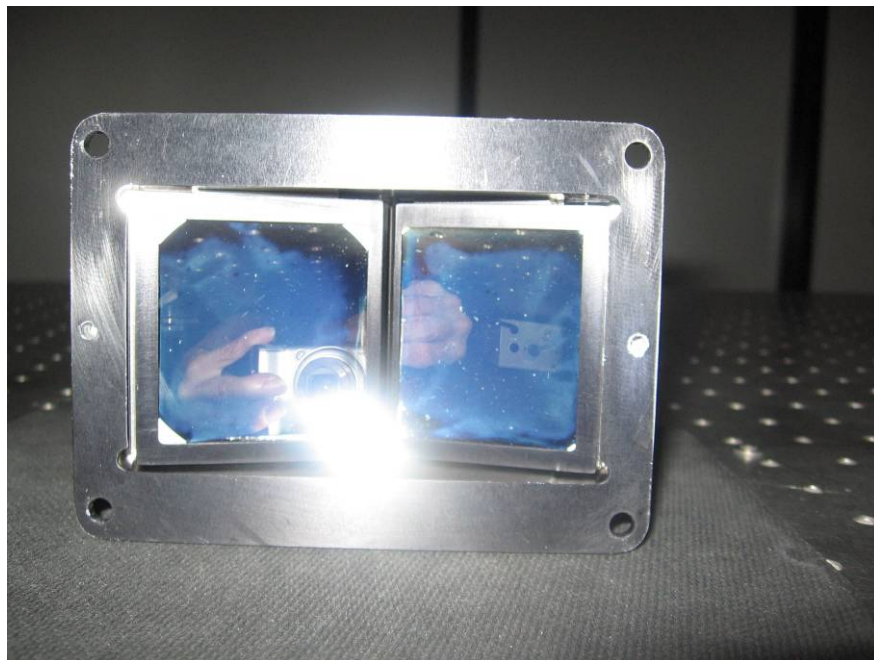


Figure 7: Spherical mirrors in their mount.

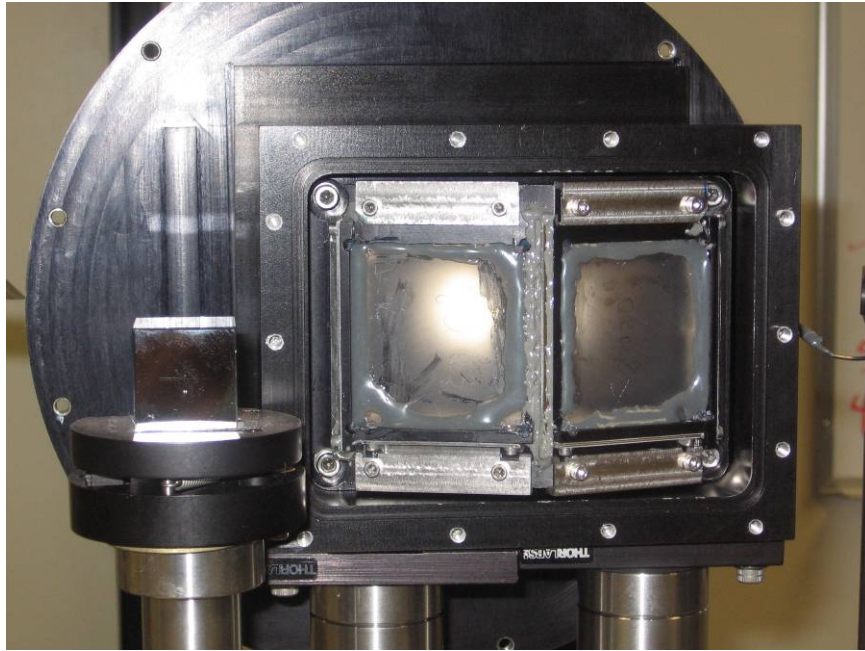


Figure 8: View of the back of the spherical mirrors with alignment cube used to ensure the integrity of the assembly set-up.

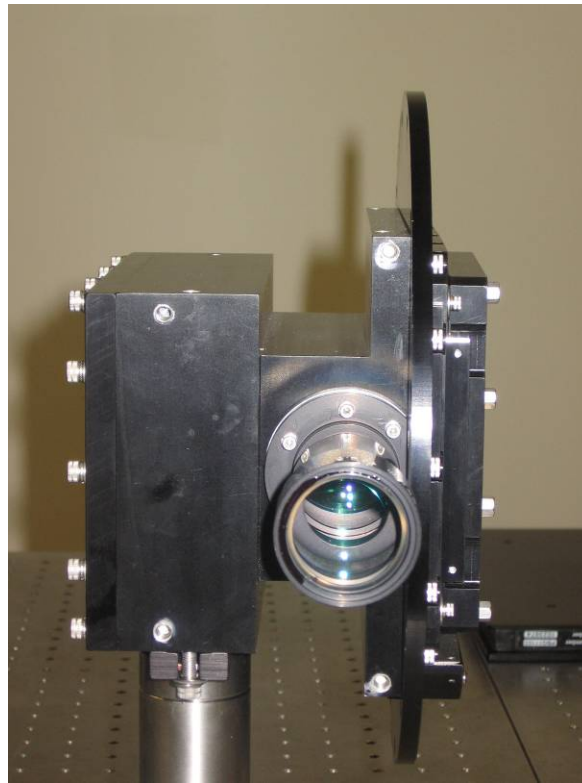


Figure 9: Completed spectrometer with foreoptic.

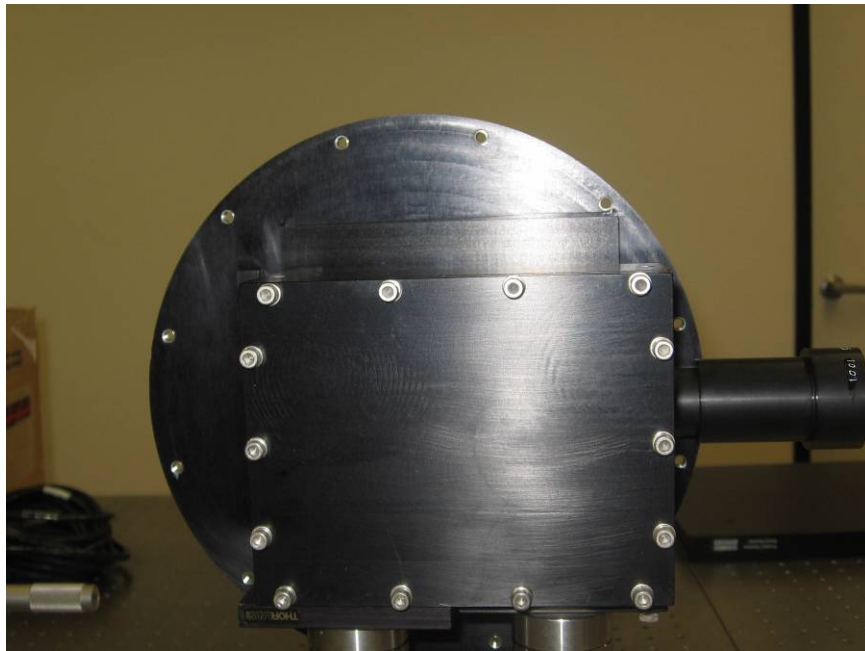


Figure 10: Side view of the spectrometer.

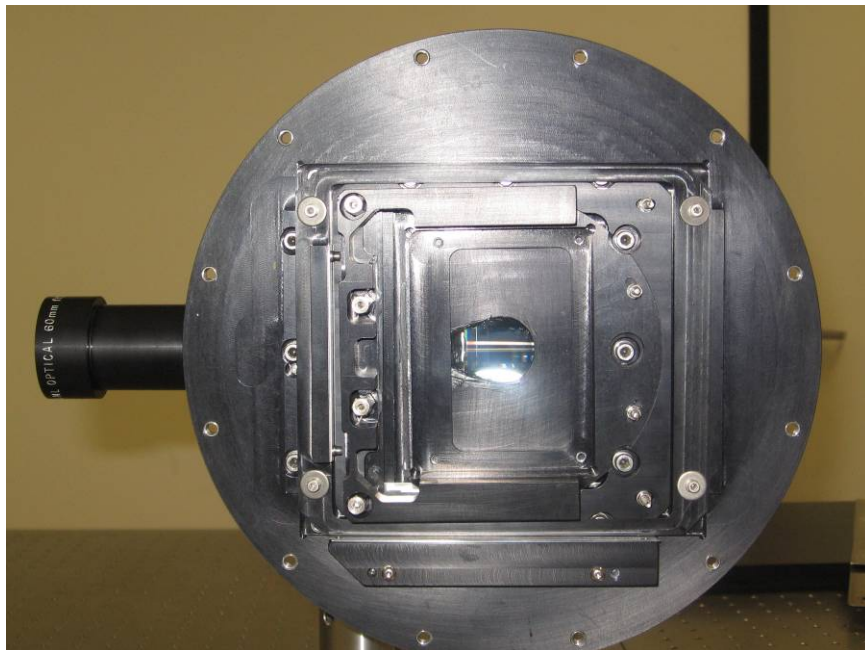


Figure 11: View of the camera mounts.

RESULTS

NOVASOL completed the design and build of a high performance hyperspectral sensor consisting of a spectrograph and a telescope lens assembly. The HICO spectrometer was shipped to the customer on September 30 2008. We expect the instrument to meet or exceed the specifications listed in Table 2. Specifically, the integration of a high efficiency grating should enhance overall system throughput, and is expected to significantly improve the SNR of the HICO sensor system. NOVASOL engineers designed the instrument with a potential launch and operation from space in mind. While the limited budget did not allow for any space qualification or appropriate documentation the design engineers were nonetheless guided by NASA parts lists and endeavored to produce a rugged overall design that will survive launch and survive operating conditions in space.

The assembly and alignment of the spectrometer would have been simpler and could have been performed faster had the camera been provided. Without the camera it was also not possible to conduct a complete verification test. However, NOVASOL did perform a visual test using a HeNe laser and a white light source to quantitatively ensure that the output looks as expected. Figures 12 and 13 show the results.

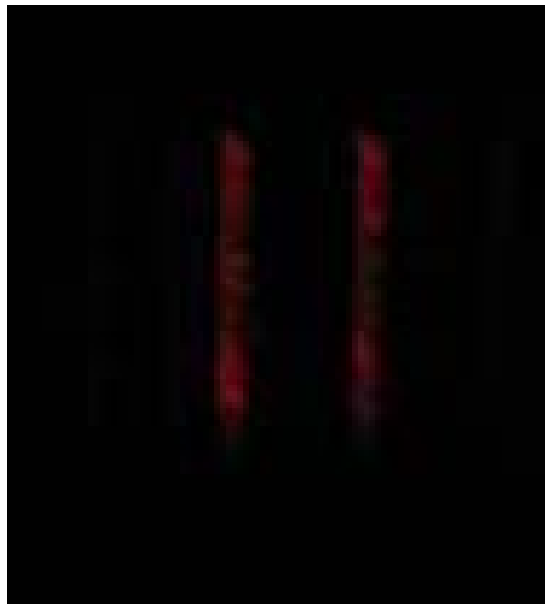
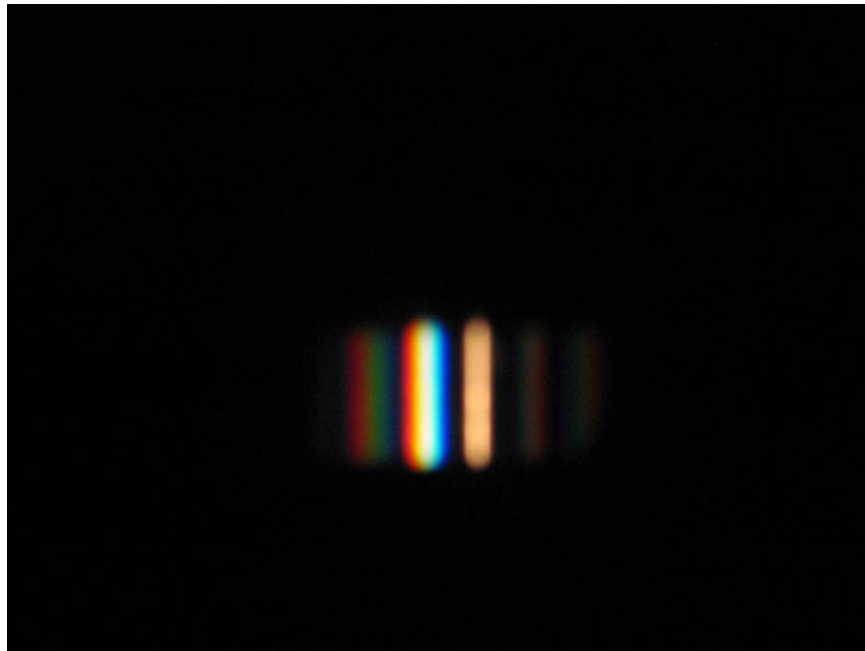


Figure 12: HeNe laser line. The line to the left is the first order and the line to the right is the second order.



*Figure 13. Close-up of White light output.
The first order is in the center.*

IMPACT/APPLICATIONS

The HICO spectrograph was designed for coastal imaging and is optimized for high throughput and SNR in the blue-green end of the optical spectrum. The design while intended for use in outer space can easily be adapted for aircraft use. The spectrometer can accommodate lenses with wide FOVs (up to 40 degrees). The design also allows for other cameras with similar focal planes, 512 x 512, with 16 micron pixels, to be integrated with the spectrograph. While the HICO spectrometer is designed specifically for a naval applications, other potential applications for this system include studies of land use and land cover, vegetation type, vegetation stress and health and crop yield.

RELATED PROJECTS

NovaSol is currently not executing any directly related projects.

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